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Factors influencing renewable energy consumption in China: An empirical analysis based on provincial panel data

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ABSTRACT

The development of renewable energy is the key to deal with climate change and low-carbon economy development in China. Here, based on a balanced panel dataset of 30 provinces in China cover the period of 1996–2013, this paper explores the effect of economic growth, CO_2 emissions, foreign trade (exports or imports) and urbanization on renewable energy consumption at the national and regional levels by using a dynamic system-GMM panel model. The empirical results show that the influence of economic growth, CO_2 emissions, foreign trade and urbanization on the renewable energy consumption is heterogeneous across regions. First, economic development has an important positive impact on renewable energy consumption in the four panels we consider and the impact is the greatest in the eastern region, follows by the national, central and western regions. Second, CO_2 emissions have a significant positive impact on renewable energy consumption in the central and national regions. However, CO_2 emissions have a weak negative impact on the consumption of renewable energy in the eastern region, and have no impact in the western region; Third, per capita exports are found to have a positive effect on the renewable energy consumption, with the greatest impact in the central region, followed by the eastern and national regions and have a weak negative impact in the western regions; Fourth, per capita imports have a negative effect on renewable energy consumption in the eastern, western and national regions and have a weak positive effect in the central region; Finally, the changes in the urbanization level significantly affect the renewable energy consumption in the four panels we consider and the impact is the greatest in the eastern region with high level of urbanization, follow by the central and western regions. On the basis of this study, we put forward the corresponding countermeasures and suggestions to achieving sustainable development in China.

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1. Introduction

In 1997, more than 100 countries and regions in the world signed the “Kyoto Protocol” and promised to promote renewable energy sources. Over the past few years, China's economy has grown at an average of over 7%. With the rapid development of economy and population, China has become the largest energy consumer and the greatest emitter of CO_2 in the world. Therefore, China government attaches great importance to promoting the work of CO_2 emissions reduction (Pang, 2015). In 2014, the Chinese government promised to reach the carbon peak in 2030 in U.S.-China Joint Announcement on Climate Change. Economic development is the most important macroeconomic goal in developing countries. Thus, how to deal with the relationship between economic development, energy consumption and environmental pollution has become the focus of policy makers and scholars concerned. The consumption of non-renewable energy (oil, coal, natural gas) is a direct cause of increased CO_2 emissions in China. The energy situation in China is also characterized by a heavy dependence on coal with a share of 76.5% in the country's primary energy consumption in 2012, followed by oil (8.9%), natural gas (4.3%) and hydro/nuclear (9.1%), (China Energy Statistics Yearbook, 2013) (National Bureau of Statistics of China, 2001–2014) respectively. Therefore, increasing the renewable energy consumption is the key to deal with climate change and low-carbon economy development in China. On February 28th, 2005, China approved a “Renewable Energy Law”, which was aimed at promoting renewable energy in the country. After the issue of this law, a great deal of renewable energy policies has been proposed. All these policies have promoted the development of renewable energy in China.

By the end of 2013, China's renewable energy power installed

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capacity had reached 3.8 million kilowatts and accounted for 30% of the total installed capacity of the whole country. The installed capacity of hydro power reached 10573.91 (10000t coal equivalent) in 2012, its consumption rate has increased from 2% to 3.1% from 1994 to 2012. The installed capacity of solar photovoltaic has increased from 0.1 million KW to 2.24 million KW from 2004 to 2011(CEC) (China Electricity Council (CEC), 2013). The installed capacity of nuclear power had reached 1364.376(10,000t coal equivalent) in 2012, its consumption rate has increased from 0.1% to 0.4% among all energy consumptions from 1994 to 2012 (China Compendium of Statistics, 1949–2008 and China Statistical Yearbook) (National Bureau of Statistics of China, 2013). To achieve the target of increasing the national share of non-fossil energy to 15% in 2020, Chinese government has set new targets in its Twelfth Five-Year Plan for nuclear and renewable energy deployment in 2015. Renewable energy is recognized as a viable option to enhance energy access and at the same time mitigate climate change (Renewable energy and climate change, 2011). The increased attention on renewable energy sources can be attributed to a number of factors. It is important to deeper understand the determinants of renewable energy consumption and to draw result implication for energy policy.

Foreign trade, economic growth, CO_2 emissions are usually acknowledged to be the key factors influencing renewable energy consumption, and their impact on renewable energy consumption are demonstrated to be heterogeneous across different countries and regions (Marques et al., 2010; Salim and Rafiq, 2012; Omri and Nguyen, 2014). Renewable energy consumption of three regions continues to grow as shown in Fig. 1 (In this paper, we use non-fossil energy consumption to represent renewable energy consumption). Fig. 1 also show regional difference is one important character of China's renewable energy consumption, and the total renewable energy consumption of the western region is higher than the central region and eastern region in China during 1996–2013. Thus, the main aim of this study was to examine the impacts of foreign trade, economic growth, CO_2 emissions and urbanization on renewable energy consumption for the entirety of China and for the three regions (i.e., eastern, central and western China, see Fig. 2).

There are a number of studies that have investigated the factors influencing renewable energy consumption. In the early stage, some scholars mainly explored the impact of economic development and CO_2 emissions on renewable energy consumption. Sadorsky (2009a) investigates the determinants of renewable

Fig. 2. Eastern, central and western regions of China.

energy consumption by using the panel co-integration method. The results show that per capita GDP and per capita CO_2 emissions have a positive impact on the per capita renewable energy consumption in the long-term relationship. Sadorsky (2009b) (Sadorsky, 2009b) uses the same method to study the links between the income and renewable energy consumption for emerging countries. The result of this study found that economic development had positive effects on renewable energy in emerging countries. Marques et al. (2010). uses fixed effect vector decomposition (FEVD) technique to explore the drivers of renewable energy in the European Union (EU) based on data from 1990 to 2006. They thought that CO_2 emissions and traditional energy sources restrain renewable deployment. In addition, per capita income has a positive correlation with renewable energy consumption. Salim and Rafiq (2012) (Salim and Rafiq, 2012) explore the determinants of renewable energy consumption in six emerging economies (Brazil, China, India, Indonesia, Philippines, and Turkey). By using the panel methods and autoregressive distributed lag (ARDL), they found that income and pollution emission are the major drivers of renewable consumption in Brazil, China, India and Indonesia.

In recent years, some scholars have explored the impact of foreign trade, foreign direct investment (FDI) and urbanization on the consumption of renewable energy. By using the dynamic system-GMM panel model, Omri and Nguyen (2014) analysis the

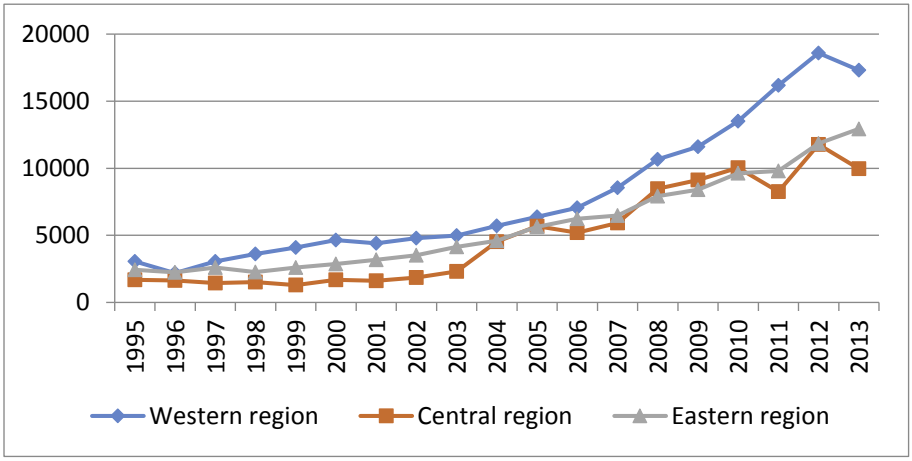

Fig. 1. Non-fossil energy consumption in eastern, middle and western regions of China from 1995 to 2013. (a) The unit of Non-fossil energy consumption is million tons of standard coal. (b) The data are from Integrated National Energy Modeling System (iNEMS) (iNEMS, 2013).

determinants of renewable energy consumption in a panel of 64 countries over the period 1990–2011. They also developed sub-panels of high, middle and low-income countries. The results of this study indicate that the increases in CO_2 emissions and trade openness are the major drivers of renewable energy consumption. Paramati et al. (2016). explore the impact of FDI inflows and stock market changes on clean energy in 20 emerging market economies. The empirical results show that the FDI inflow and the stock market changes have a significant positive impact on the clean energy consumption in the long-run relationship. The results on heterogeneous panel non-causality tests indicate that a unidirectional causal relationship was found to exist from FDI to clean energy consumption in the short-run. Lee (2013) investigates the contributions of FDI net inflows to clean energy use in 19 nations of G20 from 1971 to 2009. The test results indicate that there is no compelling evidence of FDI link with clean energy use.

There are also studies investigate the factors influencing renewable energy consumption in China. Rafiq et al (Rafiq and Alam, 2010). examine the dynamic relationships among income, CO_2 emissions and renewable energy generation in China and India from 1972 to 2011 using a multivariate vector error correction model (VECM). The results of causality test indicate that income and CO_2 emissions are the cause for renewable energy generation in the short-run for China. In the long run, for China, unidirectional causal relationship is found from income to renewable energy generation, while bidirectional causality is found between carbon emission and renewable energy generation. Lin et al. (2016). investigate the factors influencing renewable electricity consumption in China using data from 1980 to 2011 and employing the Johansen cointegration technique and vector error correction model. One finding is that there is a long-run relationship among renewable electricity consumption and GDP per capita, FDI, trade openness, financial development, share of fossil in energy consumption. Another important finding is that economic development and financial development have a positive impact on the renewable electricity consumption while FDI, foreign trade and the lobby of conventional energy sources have a negative impact on the renewable electricity consumption. The result also shows that financial development is the cause of renewable electricity consumption and renewable electricity consumption is the cause of trade openness.

Overall, a number of studies have been investigated the influencing factors of renewable energy consumption for different countries and regions. However, most of the studies did not take CO_2 emission, economic growth, urbanization and foreign trade (exports or imports) into the same framework to analysis. To our knowledge, there is no study to examine the impact of urbanization, on renewable energy consumption by using System Generalized Method of Moments (system-GMM). In addition, most existing studies have mainly focused on the relationships between CO_2 emissions, economic growth, trade openness and renewable energy consumption from a national perspective without much consideration for regional disparities for China, which may lead to a lack of understanding of the anthropogenic impacts on renewable energy consumption across China regions. Thus, the main contribution of this paper to the literature is threefold. First, this study attempts to contribute to the aforementioned literature by exploring the impacts of CO_2 emission, economic growth, urbanization and foreign trade on renewable energy consumption in China by national and regional analyses. This paper analyzes the spatial difference of renewable energy in the three regions (eastern, central and western China). Second, most of the empirical studies examining the drivers of and barriers to renewable energy employ panel unit root test and panel cointegration. This study rather estimate these relationships on the basis of a dynamic panel data model using the system generalized method of moments. This approach can corrects the endogeneity problem, fixed effects and the presence of the lagged dependent variable in panel estimation. Third, since all the variables in a growth form are stationary, our approach in this study enables us to estimate the short-run elasticities and not the long-run elasticities of renewable energy consumption to changes in exogenous variables. Finally, contrary to Lin et al (Liu and Liu, 2007). and Omri et al (Omri and Nguyen, 2014). where foreign trade is measure by the ratio imports plus exports divided by GDP, this study foreign trade is measure by per capita imports or per capita exports variable into two different specification models, to have the proper impact of each variable.

Few previous researches have introduced CO_2 emissions, economic growth and trade openness in their growth form for China. The paper fulfills this gap and contributes to the empirical literature. We also consider the role of urbanization in analyzing the evolution of renewable energy consumption. With the increasing awareness of environmental protection and sustainable development, urban residents have higher requirements on environmental quality. Thus, urban residents will pay more attention to renewable energy technologies with low energy consumption and low pollution.

The paper is structured as follows: section 2 provides the data sources and description; section 3 is the methodology; Section 4 is devoted to the empirical analysis; Section 5 concludes with policy recommendations.

2. Data sources and description

2.1. Data sources

Based on the data available and the actual needs of the research, this paper selects the panel dataset of 30 provinces in China covering the period of 1996–2013 (Hong Kong, Macao, Taiwan and Tibet are excluded for lack of data). It includes renewable energy consumption, per capita CO_2 emissions, per capita real GDP in yuan, the proportion of urban population to total population, per capita exports and per capita exports. There is no direct data on CO_2 emissions for all provinces in China. Therefore, carbon emissions are estimated by statistical yearbook and energy carbon emission coefficient. In this paper, we use non-fossil energy consumption to represent renewable energy consumption. Non-fossil energy consumption is obtained from Integrated National Energy Modeling System (iNEMS) (iNEMS, 2013).

2.2. Data description

The sample provinces of China are divided into three groups (Fig. 2): (1) eastern region consisting of 11 provinces (Liaoning, Beijing, Tianjin, Hebei, Shandong, Jiangsu, Shanghai, Zhejiang, Fujian, Guangdong, Hainan); (2) central region consisting of 8 provinces (Heilongjiang, Jilin, Shanxi, Henan, Anhui, Hubei, Hunan, Jiangxi); (3) western region consisting of 11 provinces (Xinjiang, Gansu, Qinghai, Sichuan, Yunnan, Chongqing, Guizhou, Guangxi, Ningxia, Shaanxi, Inner Mongolia).

The data of the provincial GDP, urban population, exports and imports are derived from the China Statistical Yearbook and the China Compendium of Statistics. To eliminate the influence of the price index, the GDP and foreign trade is calculated at a constant price (2005 prices). Renewable energy consumption (gRE), per capita GDP (gY), per capita CO_2 emissions (gCO_2), and per capita exports (gEX) and per capita imports (gIM) are measured in the growth form as they are not stationary in levels. Urbanization (U) is stationary its level form, and therefore no transformation is required. Table 1 shows the statistical description of the variable in 30 Chinese provinces from 1996 to 2013.

Table 1
Summary statistics of the variables.

Variables	Obs	Mean	Std. Dev.	Min	Max
gRE	540	0.180	0.665	−0.963	4.242
gY	540	0.136	0.063	0.001	0.445
gCO_2	540	0.070	0.373	−0.807	5.807
gEX	540	0.200	0.476	−0.798	6.598
gIM	540	0.213	0.310	−0.759	2.728
U	540	0.439	0.165	0.139	0.896

It can be seen from Fig. 3 that the annual mean of renewable energy consumption, CO_2 emissions, GDP, exports, imports and urbanization from 1996 to 2013. Guangdong, Hubei, Sichuan had the highest renewable energy consumption in eastern, central and western China, followed by some provinces like Fujian, Zhejiang, Yunnan (as shown in Fig. 3a). The provinces with the highest CO_2 emissions are concentrated in eastern regions, such as Beijing, Hebei, Shandong and Liaoning provinces, followed by the central province like Henan, Shanxi and Inner Mongolia (as shown in Fig. 3b). Guangdong, Zhejiang, Jiangsu, Shanghai and Beijing had the highest GDP, exports and imports in eastern coastal and central China (as shown in Fig. 3c, d, e. The high level of urbanization is mainly distributed throughout eastern coast and Northeast China, including Guangdong, Jiangsu, Jilin, Heilongjiang and other provinces (as shown in Fig. 3f). Per capita renewable energy consumption, CO2 emissions, GDP, exports, imports and urbanization in 1996 and 2013 are showed in Fig A.1-2 in Appendix A.

3. Methodology

3.1. Estimating energy-related CO_2 emissions in China province

There is no direct data on carbon dioxide emissions for all provinces in China. Therefore, carbon emissions are estimated by statistical yearbook and energy carbon emission coefficient. With reference to Du et al. (2012), we calculated CO_2 emissions for China covering the period 1996–2013 by using the CO_2 emissions coefficients published by the Intergovernmental Panel on Climate Change (IPCC) (Intergovernmental Panel on Climate Change (IPCC), 2007) and the National Coordination Office on Climate Change and the Energy Research under the National Development and Reform Commission (National Coordination Com, 2007). Energy-related CO_2 emissions can be calculated using Eq. (1).

$$CO_2 = \sum_{i=1}^{7} E_i \cdot F_i + Q \cdot C \tag{1}$$

Where$iCO_2 E_i F_i, C$ and Q denote the different types of fossil fuel, the total CO_2 emissions, the i th kind of primary energy consumption, the CO_2 emissions coefficients of fossil fuels, the CO_2 emissions coefficient of the cement production process (Table 2), the quantity of cement production, respectively. Fig. 3b shows the annual mean of CO_2 emissions from 1996 to 2013.

3.2. Explanatory variables

The main aim of this study was to examine the impacts of CO_2 emission, economic growth, urbanization and trade openness on renewable energy consumption in China by national and regional analyses. We use dynamic panel data model to analyze the relationship between variables. This approach can overcome the problem of endogeneity, fixed effects and the presence of the lagged dependent variable in panel estimation. We select the variables to include in the system based on the economic theory and available empirical evidence.

First, China has been recognized as one of the world's fastest developing countries, specifically for its rapid urbanization in the past decades (Bao and Fang, 2012). The improvement of the

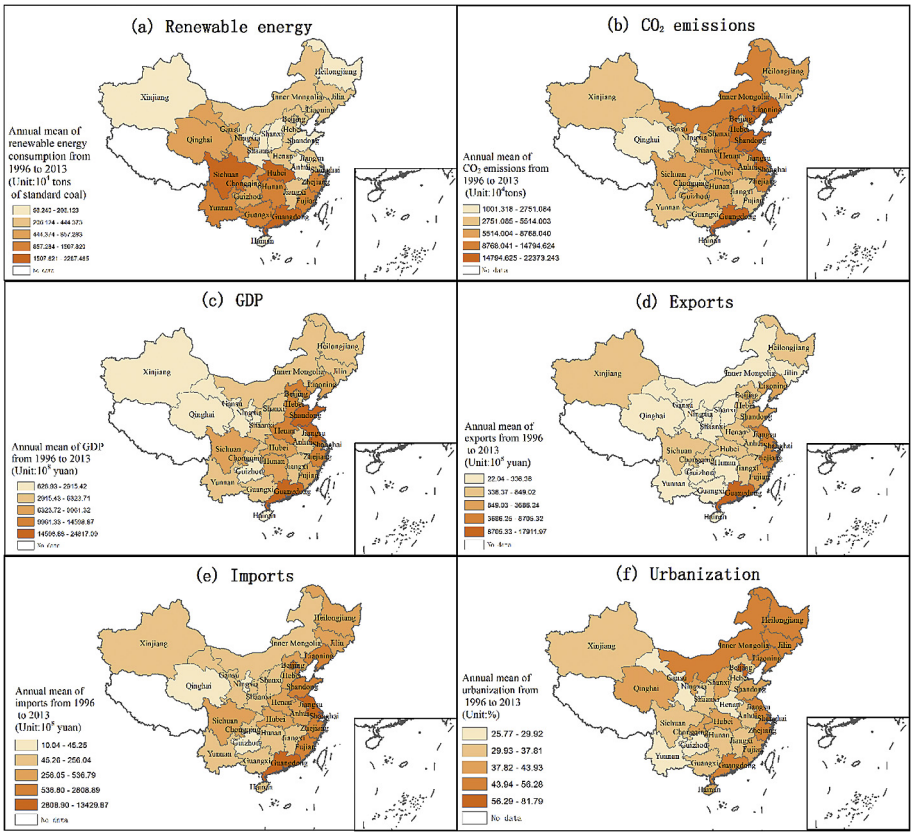

Fig. 3. The annual mean of renewable energy consumption, CO_2 emissions, GDP, exports, imports and urbanization from 1996 to 2013.

Table 2
CO_2 emissions coefficients.

Sources	Coal	Coke	Gasoline	Kerosene	Diesel	Fuel oil	Natural gas	Cement
CO_2 emissions coefficient	1.647	2.848	3.045	3.174	3.150	3.064	21.670	0.527

Source: IPCC and the National Coordination Committee Office on Climate Change and Energy Research Institute under the National Development and Reform Commission.

urbanization level, not only means the increase of urban population, but also affects the change of industrial structure, economic growth, the consumption level of residents and other aspects. These changes are likely to affect China's renewable energy consumption. Urban population, urban scale is expanding in the process of urbanization for China. With the increasing awareness of environmental protection and sustainable development, urban residents have higher requirements on environmental quality. Thus, urban residents will pay more attention to renewable energy technologies with low energy consumption and low pollution. A large number of studies have also shown that the level of urbanization plays an important role in energy consumption (Wang and Wei, 2014; Salim and Shafiei, 2014; Tan et al., 2016). Moreover, Yang and Zhang (Yang et al., 2016) also believe that the level of urbanization is one of the main driving forces to promote renewable energy consumption. Therefore, this paper takes the urbanization level as one of the explanatory variables to study the influencing factors of renewable energy consumption.

Second, import and export trade is also an important factor which affects energy consumption. Since China's enter into the WTO, the total import and export trade increased from 6208 billion dollars in 2002–43602 billion dollars in 2013, with an average annual growth rate of 19.4%. Foreign trade not only promotes economic development but also increases energy consumption in China. In additional, the total volume of imports and exports of renewable energy products had increased from 10 billion 600 million dollars in 1996 to 239 billion 600 million dollars in 2011, with an average annual growth rate of 29.1%. Indeed, exports can induce more renewable energy production because the increase in export volume will stimulate renewable energy consumption, which will promote more energy and renewable energy to produce and transport these traded goods to foreign countries. At the same time, import and export trade can play an important role in greening the energy sector because it can lead to the transferring of renewable energy technology. Moreover, Omri and Nguyen (2014) have studied the impact of foreign trade on renewable energy consumption and show that trade openness is one of the main driving forces to promote renewable energy consumption. Therefore, explaining the impact of import and export trade on renewable energy consumption is particularly interesting for the China case.

Third, the Intergovernmental Panel on Climate Change (IPCC) in its 2007 pointed out that global CO_2 concentration would continues to rise in the future and fossil fuelled economic growth, through its release of CO_2 into the atmosphere, is the main driver behind global warming. With the rapid development of economy and population, China has become the largest energy consumer and the greatest emitter of CO_2 in the world. People are beginning to worry that the continuous emission of carbon dioxide would have disastrous consequences. In that way, a high level of CO_2 emissions gives rise to encourage the development and use of renewable energy. In additional, some studies have exported the impact of CO_2 emissions on renewable energy consumption and show that CO_2 emissions is one of the main driving forces to promote renewable energy consumption (Omri and Nguyen, 2014; Sadorsky, 2009a, 2009b; Menegaki, 2011). Thus, carbon dioxide emissions are incorporated into this dynamic model framework as an important explanatory variable.

Finally, from an economic point of view, economic growth not only has a strong dependence on energy consumption but also promote the sustainable use of energy (Liu and Liu, 2007). This is because economic growth should lead to a high level of renewable energy consumption under pressure of increasing environmental degradation and climate change. Over the past few years, China's economy has developed rapidly and become the second largest economy in the world behind the United States. However, the rapid economic development has been accompanied by huge energy consumption and environment issues. Moreover, a number of studies have explored the impact of economic development on renewable energy consumption and show that economic development is the most important driving forces to promote renewable energy consumption (Rafiq and Alam, 2010; Lin et al., 2016; Menegaki, 2011; Chang et al., 2009; Tugcu et al., 2012).

3.3. Empirical model and estimation procedure

The aim of this study is to investigate the dynamic relationship between renewable energy consumption (RE), per capita CO_2 emissions (CO_2), per capita real GDP (Y), urbanization (U) and foreign trade (TR), we specify the following empirical model:

$$RE = f(Y, CO_2, TR, U) \tag{2}$$

Considering the high correlation between exports and imports, foreign trade variable will be incorporated by including per capita exports (EX) and per capita exports (IM) into two separate models (in growth form with a time series specification):

$$gRE_t = a_0 + a_1 gY_t + a_2 gCO_{2t} + a_3 gEX_t + a_4 U_t + \varepsilon_t \tag{3}$$

$$gRE_t = b_0 + b_1 gY_t + b_2 gCO_{2t} + b_3 gIM_t + b_4 U_t + \varepsilon_t \tag{4}$$

Since our study is a panel data study, Eqs. (3) and (4) can be written in panel data form as follows:

$$gRE_{i,t} = a_0 + a_1 gY_{i,t} + a_2 gCO_{2i,t} + a_3 gEX_{i,t} + a_4 U_{i,t} + \varepsilon_{i,t} \tag{5}$$

$$gRE_{i,t} = b_0 + b_1 gY_{i,t} + b_2 gCO_{2i,t} + b_3 gIM_{i,t} + b_4 U_{i,t} + \varepsilon_{i,t} \tag{6}$$

where the subscript $i(i=1, \ldots, N)$ denotes the provinces i in our sample, with N being equal to 30; $t(t=1, \ldots, T)$ denote the time; gRE is the growth rate of total renewable energy consumption; gY indicates the growth rate of per capita GDP; gCO_2 represents the growth rate of per capita CO_2 emissions; gEX represents the growth rate of per capita export; gIM represents the growth rate of per capita import;U denotes the urbanization.

We examine the impacts of urbanization, CO_2 emission, economic growth, and foreign trade on renewable energy consumption by using system-GMM estimator proposed by Arellano and Bover (1995) and Bundell and Bond (Blundell and Bond, 1998). There are three reasons for utilizing system-GMM estimator in panel data estimations. Firstly, system-GMM estimator yields efficient and consistent parameter estimates in a regression, of which the regressors are not strictly exogenous (Roodman, 2009). Secondly, system-GMM is advantageous in that it helps solve the issues

of fixed effects and endogeneity of regressors (Nickell, 1981). Thirdly, this method can effectively improve the consistency and validity of the estimation results by using the lag period of the internal variables as the instrumental variables. Finally, there are two types of GMM estimators (difference and system) and they can be both alternatively considered in there one-step and two-step versions. The estimations by system-GMM estimator are more efficient and allowing for more instruments through an additional assumption than difference-GMM which proposed by Arellano and Bond (1991). A system with the original equation in levels and the transformed equation in first differences compose System GMM estimator. The general model of the data generating process of System GMM estimator is given as:

The first-order autoregressive panel data model is

$$\begin{aligned} y_{i,t} &= \alpha y_{i,t-1} + \beta X'_{i,t} + u_{i,t} \\ u_{i,t} &= \eta_i + \varepsilon_{i,t} \end{aligned} \tag{7}$$

where $X'_{i,t}$ is the vector of explanatory variables, $u_{i,t}$ is the disturbance term, $\eta_i$and $\varepsilon_{i,t}$denote fixed effects and idiosyncratic shocks, respectively, which are assumed to have an error components structure with

$$E(\eta_i) = 0, E(\varepsilon_{i,t}) = 0, E(\varepsilon_{i,t}\eta_i) = 0 \;\; \mathrm{i} = 1, \ldots, \mathrm{n}; \;\; \mathrm{t} = 2, \ldots, \mathrm{T} \tag{8}$$

$$E(\varepsilon_{it}\varepsilon_{is}) = 0 \;\; \mathrm{i} = 1, ., \mathrm{n} \;\; t \neq s \tag{9}$$

The initial condition provides

$$E(y_{i1}\varepsilon_{it}) = 0 \text{ for } t \geq 2 \tag{10}$$

$$E(\eta_i \Delta y_{i2}) = 0 \tag{11}$$

Under assumptions (8), (9), (10) and (11), linear moment conditions are

$$E\left(y_{i,t-s}\Delta u_{it}\right) = 0 \;\; \text{for } t \geq 3 \text{ and } s \geq 2 \tag{12}$$

$$E\left(u_{it}\Delta y_{i,t-1}\right) = 0 \text{ for } t \geq 3 \tag{13}$$

For the consistency of System GMM estimations, it is important to assure two key conditions: i. There should be no serial correlation in the error term. ii. The instruments should not be correlated with the error term.

The empirical model to be estimated can be rewritten as Eqs. (14) and (15):

$$\begin{aligned} gRE_{i,t} &= a_0 gRE_{i,t-1} + \sum_{j=1}^{4} \beta X'_{i,t} + \eta_i + \phi_t + \varepsilon_{i,t}, i = 1, \ldots, 30; t \\ &= 1996, \ldots, 2013 \end{aligned} \tag{14}$$

$$\begin{aligned} gRE_{i,t} &= b_0 gRE_{i,t-1} + \sum_{j=1}^{4} \beta Z'_{i,t} + \eta_i + \phi_t + \varepsilon_{i,t}, i = 1, \ldots, 30; t \\ &= 1996, \ldots, 2013 \end{aligned} \tag{15}$$

where $gRE_{i,t}$ indicates the growth rate of the province i's renewable energy consumption at time t. X and Z are a vector of core explanatory variable used to model renewable energy consumption. X includes four variables: CO_2 emissions, urbanization, economic development and exports. Z includes four variables: CO_2 emissions, urbanization, economic development and imports.η andϕ stand for province-specific effect and time-specific effects, respectively. ε is an error term. a_0 and b_0 are the parameters to be estimated.

4. Empirical analysis

4.1. Panel unit root tests

We test the stability of variables to decide which variables should enter the empirical model in their growth form or in their level form. Im et al. (2003). and Levin et al. (2002). proposed the IPS and LLC panel unit root tests, respectively. The key difference between the IPS and LLC tests is that the LLC test sets the unit root null hypothesis against the alternative hypothesis where all sectoral real exchange rates are stationary, while the IPS test relaxes these homogeneity restrictions under the alternative hypothesis. IPS and LLC are used to start our analysis. All unit root statistics reported inTables 3 and 4 for the four panels under consideration: eastern panel, central panel, western panel and national panel. Both of the results show that urbanization is stationary and can enter the empirical model without being transformed into growth form. However, the remaining variables (per capita CO_2 emissions, per capita real GDP, per capita foreign trade and renewable energy consumption) are non-stationary. Thus, they have to be transformed into the growth form.

4.2. Parameters estimates

After the stability of variables is determined, we run the empirical model of Eqs. (14) and (15) by using two-step system-GMM estimator. Estimated coefficients are computed for all the four panels. The estimation results are reported in Tables 5 and 6.

In the exports (resp. imports) model, regarding the eastern region panel, the results of the coefficient calculated by two-step sys-GMM indicate that economic growth, CO_2 emissions, exports and urbanization have a positive and statistically effects on renewable energy consumption. The elasticity coefficient of economic growth, CO_2 emissions, exports and urbanization to renewable energy consumption are 1.907 (resp. 2.122), 0.078 (resp. 0.039), 0.135 and 0.854 (resp. 0.951), respectively. The result implies that a 1% increase in the per capita GDP, per capita CO_2 emissions, per capita exports and urbanization level raises the per capita renewable energy consumption of eastern region by 1.907% (resp. 2.122%), 0.078% (resp. 0.039%), 0.135% and 0.854% (resp. 0.951%), respectively. In additional, for the model with imports, the impact of imports on renewable energy consumption is weak and statistically insignificant. Thus, economic growth and urbanization are important contributors to renewable energy consumption in eastern region. This result shows that economic development and urbanization are the main driving force for renewable energy consumption in the eastern region. The important impacts from economic growth and urbanization can be explained by the fact that with the rapid economic development and the high level of

Table 3
Results of the IPS panel unit root test for the variables in level.

	eastern region		central region		western region		national region	
	Statistic	Prob.	Statistic	Prob.	Statistic	Prob.	Statistic	Prob.
RE	6.419	1.000	2.289	0.989	2.197	0.986	6.287	1.000
Y	8.428	1.000	7.100	1.000	5.967	1.000	3.179	0.999
CO_2	5.547	1.000	3.351	0.999	2.235	0.987	10.884	1.000
EX	4.051	0.982	3302	1.000	6.979	1.000	7.330	1.000
IM	8.350	1.000	3.222	0.950	6.919	1.000	8.295	1.000
U	−5.798*	0.0022	−2.295*	0.009	−7.083*	0.0001	−6.4485*	0.000

Notes: *Statistical significance at the 1% level.

Table 4
Results of the LLC panel unit root test for the variables in level.

	eastern region		central region		western region		national region	
	Statistic	Prob.	Statistic	Prob.	Statistic	Prob.	Statistic	Prob.
RE	6.632	1.000	2.559	0.7120	4.204	1.000	6.215	1.000
Y	8.206	1.000	7.187	1.000	5.685	1.000	2.791	0.997
CO_2	4.340	1.000	3.183	0.999	2.669	0.996	8.710	1.000
EX	3.020	0.998	4.143	1.000	6.979	1.000	5.253	1.000
IM	6.578	1.000	3.996	0.962	6.919	1.000	8.143	1.000
U	−3.101*	0.001	−2.295*	0.009	−3.793*	0.000	−4.448*	0.000

Notes: *Statistical significance at the 1% level.

urbanization in the eastern region of China, the urban residents are well paid and willing to use renewable energy sources. In additional, CO_2 emissions and exports also contributed to the development of renewable energy consumption in the eastern. The proportion of China's renewable energy products was increasing, which increased the consumption demand of renewable energy sources after China joined WTO. Meanwhile, most of the port cities in China are concentrated in the eastern region. With the continuous increase of CO_2 emissions, the eastern residents will actively use renewable energy in order to improve the quality of the environment.

In the exports (resp. imports) model, for the central region panel, the estimate result indicates that economic growth, CO_2 emissions, exports and urbanization have a positive and statistically effects on renewable energy consumption. The elasticity coefficient of renewable energy production to economic growth, CO_2 emissions, exports and urbanization are 0.581 (resp. 0.563), 0.134 (resp. 0.172), 0.341 and 0.686 (resp. 0.679), respectively. Effectively, a 1% increase in the per capita GDP, per capita CO_2 emissions, per capita exports and urbanization leads to increase the renewable energy consumption by around 0.581% (resp. 0.563%), 0.134% (resp. 0.172%), 0.341% and 0.686% (resp. 0.679%), respectively. The result is similar to that of Sadorsky (2009a), Salim et al (Salim and Rafiq, 2012). and Omri et al (Omri and Nguyen, 2014). who show that pollutant emissions and economic growth are major drivers of renewable energy consumption. Notably, however, the result is not consistent with Marques et al. (2010). who show that CO_2 emissions restrain renewable deployment for the Europe case. For the model with imports, the impact of imports on renewable energy consumption is weak and statistically insignificant in the central region. The absence of significant impact from import may be explained by the fact that the central region is dominated by coal energy consumption and the proportion of renewable energy to the total imported energy is low in the central region.

In the exports (resp. imports) model, regarding the western region panel, the findings reveal that economic growth and urbanization have a positive and statistically effects on renewable energy consumption. Typically, a 1% increase in the per capita GDP and urbanization raises the renewable energy consumption of western region by around 0.392% (resp. 0.462%) and 0.395% (resp. 0.438%), respectively. These results suggest that the renewable energy consumption will be gradually increased with the increasing in the per capita GDP and urbanization level in the western region. However, for both models, the impact of CO_2 emissions on renewable energy consumption is statistically insignificant. The reason for this result may be that although CO_2 emissions in the western region have been increasing in recent years, urban residents have no additional income to pay for renewable energy consumption. Moreover, per capita exports and per capita imports have a weak negative impact on renewable energy consumption in the western region. This result can be explained by the fact that the scale of foreign trade in Western China is small. According to statistics in 2013 China's total foreign trade in the western region accounted for 6.6% of the total foreign trade of China.

The results for the national region panels are very similar to those for the central region panels. In the exports (resp. imports) model, the elasticity coefficient of per capita GDP to renewable energy consumption is 0.911 (resp. 0.929) which suggests that

Table 5
Two-step system-GMM panel estimation regression with exports variable.

Dependent variable	*RE*			
	Eastern region	Central region	Western region	National region
Y	1.907** (0.023)	0.581*(0.079)	0.392** (0.012)	0.911*** (0.000)
CO_2	0.078* (0.054)	0.134*(0.086)	0.087 (0.362)	0.107***(0.000)
EX	0.135* (0.071)	0.341*** (0.004)	−0.082*(0.079)	0.050** (0.022)
U	0.854 ** (0.271)	0.686** (0.035)	0.395*(0.086)	0.594* (0.052)
Constant	0.074* (0.08)	0.377* (0.088)	−0.642**(0.049)	0.579* (0.086)
Hansen J-test (p-value)	21.530(0.853)	15.620(0.360)	16.450(0.667)	19.150(0.923)
AR2 test (p-value)	0.390(0.699)	0.360(0.353)	0.420(0.732)	0.380(0.706)

Notes: ***, ** and * Indicates statistical significance at the 1%, 5% and 10% level. Values in parenthesis are the estimated p-values. Hansen J-test refers to the over-identification test for the restrictions in GMM estimation. The AR2 test is the Arellanon-Bond test for the existence of the second-order autocorrelation in first differences.

Table 6
Two-step system-GMM panel estimation regression with imports variable.

Dependent variable	*RE*			
	Eastern region	Central region	Western region	National region
Y	2.122** (0.011)	0.563*(0.086)	0.462** (0.035)	0.929***(0.034)
CO_2	0.039* (0.074)	0.172*(0.065)	0.159 (0.536)	0.073*(0.067)
IM	−0.096 (0.371)	0.050 (0.594)	−0.016*(0.083)	−0.066*(0.083)
U	0.951** (0.013)	0.679***(0.000)	0.438**(0.046)	0.518*** (0.007)
Constant	−0.182*** (0.002)	−0.030* (0.058)	−0.151**(0.047)	−0.103* (0.082)
Hansen J-test (p-value)	20.360(0.758)	17.35(0.698)	16.86(0.496)	19.840(0.923)
AR2 test (p-value)	0.560(0.340)	0.380(0.256)	0.480(0.391)	0.350(0.729)

Notes: ***, ** and * Indicates statistical significance at the 1%, 5% and 10% level. Values in parenthesis are the estimated p-values. Hansen J-test refers to the over-identification test for the restrictions in GMM estimation. The AR2 test is the Arellanon-Bond test for the existence of the second-order autocorrelation in first differences.

there is an obvious positive correlation between economic growth and renewable energy consumption. Thus, the continuous improvement of the economic level is conducive to renewable energy consumption. This result is similar to that of Lin (Lin et al., 2016), Rafiq (Rafiq et al., 2014), Sadorsky (2009b) and Salim et al (Salim and Rafiq, 2012). who show that economic growth is the major driver of renewable consumption. However, this result is contrary to that of Menegaki (2011) who suggests that there is no obvious causality between renewable energy consumption and GDP for the Europe case. According to the actual situation of China, with the rapid development of economy, the environmental problems and energy crisis are becoming more and more serious in recent years. Thus, the Chinese government attaches great importance to the development and utilization of renewable energy, and gives practical support in terms of capital, laws and policies. For example, China continued to implement the "renewable energy law" promulgated in 2005. The elasticity coefficient of per capita CO_2 emissions to renewable energy consumption is 0.107 (resp. 0.073). This result shows that CO_2 emissions are contributor to renewable energy consumption in China. Meanwhile, a 1% increase in the per capita exports raises the renewable energy consumption of China by around 0.050% for the model with exports. This result indicates that exports promote the consumption of renewable energy. This finding is consistent with the fact that the proportion of renewable energy exports products to total exports is rising, such as China's photovoltaic cell production accounted for 56.5% of global production in 2011. In additional, per capita imports have a weak negative effect on the consumption of renewable energy in the imports model. The reason for this result may be that fossil fuels still dominate in China's energy imports, such as China's crude oil and coal imports reached 3.1 million tons and 2.9 million tons in 2014, respectively. Thus, although imports can introduce high-tech and high-tech talents to a certain extent, it does not effectively improve renewable energy consumption. Another reason for this result may be that China does not make full use of the advanced technology and management experience of foreign investment to improve the renewable energy consumption. In general, exports and imports do not seem to have very strong impact on renewable energy consumption in China. This result is similar to that of Lin et al. (2016). for the China case. However, the result is not consistent with Omri et al (Omri and Nguyen, 2014). who show that trade openness is the major influencers of renewable energy for the 64 countries in the world. Finally, the elasticity coefficient of urbanization has a statistically significant and positive impact on renewable energy consumption in China for both models. The result is consistent with the empirical analysis that with the continuous improvement of the level of urbanization, urban residents have higher requirements on environmental quality and are willing to pay more attention to renewable energy technologies with low energy consumption and low pollution. In the process of urbanization, the urban population and the scale of cities are expanding, and the awareness of environmental protection and sustainable development of urban residents are also deepening. Thus, the renewable energy technologies with low energy consumption and low pollution have attracted more and more attention of urban residents. Meanwhile, China proposes the National New Type Urbanization Plan (2014–2020) clearly pointed out that China will integrate ecological civilization into the development of urbanization. Moreover, this result is similar to that of Yang and Zhang (Yang et al., 2016) who shows that the level of urbanization is one of the main driving forces to promote renewable energy consumption for China case. However, the result is not consistent with Salim and Shafiei (2014) who suggests that urbanization has no obvious impact on renewable energy consumption in OECD countries.

In the exports (resp. imports) model, the influence of economic growth, CO_2 emissions, foreign trade and urbanization on renewable energy consumption is also heterogeneous across regions. First, the elasticity of per capita GDP to renewable energy consumption is 1.907 (resp. 2.122) in the eastern region, larger than the elasticity in the central, western and national regions. This finding reveals that economic growth have a positive effect on renewable energy consumption in the four regions, and the impact is the greatest in the eastern region, follows by the national, central and western regions. The reason for this result may be that economic development in the eastern region is significantly faster than central and western region. In additional, the residents in the eastern region have more disposable income to which can be used to develop environmental-friendly technology and energies. Moreover, residents in the eastern region with high-income levels have more concerns for the environment. Second, for the both models, the positive effect of per capita CO_2 emissions on renewable energy consumption varied across the three regions, with the greatest impact in the central region, followed by the eastern and national regions. The central region has a large amount of coal and oil resources, and provides energy for the whole country. In additional, the energy consumption structure dominated by coal and oil in central region has led to the rapid increase of carbon dioxide emissions. Thus, a high level of CO_2 emissions creates pressure for the environmental cleaning policy and the demand for urban residents to change the deteriorating environment is more intense. Third, in the exports model, per capita exports are found to have a positive effect on the renewable energy consumption, with the greatest impact in the central region, followed by the eastern and national regions. However, per capita exports have a weak negative impact on the consumption of renewable energy in the western regions. In additional, in the imports model, per capita imports have a negative and statistically effects on renewable energy consumption in the eastern, western and national regions and have a positive effect in the central regions. Finally, in the exports (resp. imports) model, the elasticity of urbanization to renewable energy consumption is 0.854 (resp.0.951) in the eastern region, larger than the elasticity in western regions, central region and national region (0.594). As the eastern region was the first involving in the Reform and Open in China, the urbanization level in eastern is higher than that in eastern and western regions. With the increasing awareness of environmental protection and sustainable development, urban residents in eastern region have higher requirements on environmental quality. Thus, urban residents will pay more attention to renewable energy technologies with low energy consumption and low pollution.

5. Conclusions and policy implications

Based on a balanced and high-quality panel dataset of 30 provinces in China covering the period of 1996–2013, this study uses a dynamic panel data model to estimate the impact of economic growth, CO_2 emissions, foreign trade (exports or imports) and urbanization on renewable energy consumption in whole of China and its three parts (eastern, central and western regions).

The results from two-step system-GMM show that (i) economic development have an important positive impact on renewable energy consumption in the four panels we consider and the impact is the greatest in the eastern region, follows by the national, central and western regions; (ii) CO_2 emissions have a significant positive impact on renewable energy consumption in the central and national regions. However, the impact of CO_2 emissions on renewable energy consumption in the eastern and western regions is not particularly obvious; (iii) per capita exports are found to have a positive effect on the renewable energy consumption, with the

greatest impact in the central region, followed by the eastern and national regions and have a weak negative impact in the western regions; (iv) per capita imports have a negative effect on renewable energy consumption in the eastern, western and national regions and have a weak positive effect in the central region; (v) the changes in the urbanization significantly affect the renewable energy consumption in the four panels we consider and the impact is the greatest in the eastern region with high level of urbanization, follows by the central, national and western regions.

Empirical finding enable us to draw some policy implications regarding renewable energy consumption in China. First, to the extent that economic growth has a positive effect on renewable energy consumption in the four regions. The impact is the greatest in the eastern region with high-income, follows by the central and western regions. This means that people in the eastern region have higher requirements on environmental quality and urge the governments to increase the use of renewable energy. In this context, China must continue to design policies include economic landscape free of corruption and good monetary and fiscal policies encourage promote economic growth to promote sustainable economic development. Second, CO2 emissions have a positive impact on renewable energy consumption in the eastern, central and national regions. Thus, China has to increase the proportion of renewable energy in energy consumption and reduce the consumption of non-renewable energy and tax fossil fuels to subsidize the use of renewable energy. In the western region, CO2 emissions have no significant impact on energy consumption. Thus, Government departments should strengthen environmental protection publicity, so as to enhance the awareness of environmental protection of low-income residents. Meanwhile, government departments should implement preferential pricing policies for renewable energy in low-income areas in western region. Third, exports and imports do not seem to have very strong impact on renewable energy consumption in China, and per capita imports have a weak negative impact on renewable energy consumption in national region. Thus, China should continue to speed up the development of low carbon trade and improve the proportion of renewable energy products in the exports and imports. In additional, Chinese enterprises should give full play to the advantages of clean production technology brought by foreign trade, and increase the proportion of renewable energy consumption to total energy consumption. Finally, the finding that urbanization has a positive effect on renewable energy consumption in the four regions, and the impact is the greatest in the eastern region with high level of urbanization, follows by the central and western regions. In that way, China should continue to implement the National New Type Urbanization Plan (2014–2020) to integrate ecological civilization into the development of urbanization. Chinese government must continue to encourage the adjustment of industrial structure and energy consumption structure in the process of urbanization and promote the development of low-carbon urbanization. Moreover, Chinese government should adjust the fiscal policies to support green construction and expand the scale of green buildings.

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Appendix A

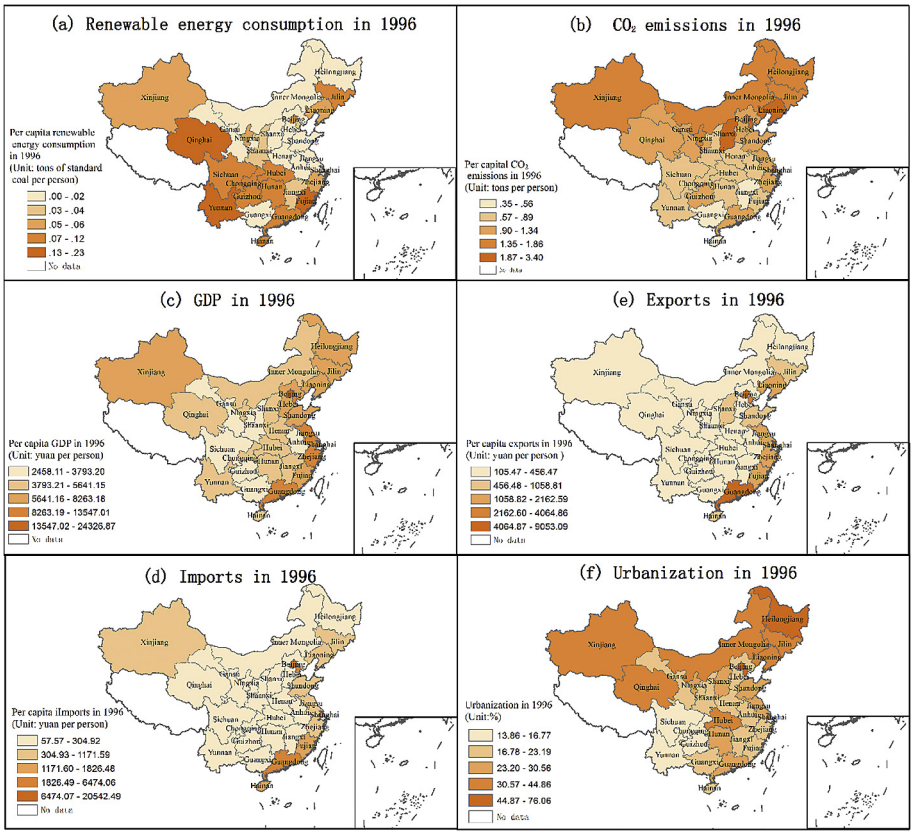
(a) Renewable energy consumption in 1996
Per capita renewable energy consumption in 1996 (Unit: tons of standard coal per person)
.00 - .02
.03 - .04
.05 - .06
.07 - .12
.13 - .23
No data
(b) CO2 emissions in 1996
Per capital CO2 emissions in 1996 (Unit: tons per person)
.35 - .56
.57 - .89
.90 - 1.34
1.35 - 1.86
1.87 - 3.40
(c) GDP in 1996
Per capita GDP in 1996 (Unit: yuan per person)
2468.11 - 3793.20
3793.21 - 5641.15
5641.16 - 8263.18
8263.19 - 13547.01
13547.02 - 24326.87
(e) Exports in 1996
Per capita exports in 1996 (Unit: yuan per person)
105.47 - 456.47
456.48 - 1058.81
1058.82 - 2162.59
2162.60 - 4064.86
4064.87 - 9053.09
(d) Imports in 1996
Per capita iImports in 1996 (Unit: yuan per person)
57.57 - 304.92
304.93 - 1171.59
1171.60 - 1826.48
1826.49 - 6474.06
6474.07 - 20542.49
(f) Urbanization in 1996
Urbanization in 1996 (Unit:%)
13.86 - 16.77
16.78 - 23.19
23.20 - 30.56
30.57 - 44.86
44.87 - 76.06

Fig. A.1. Per capita renewable energy consumption, CO_2 emissions, GDP, exports, imports and urbanization in 1996.

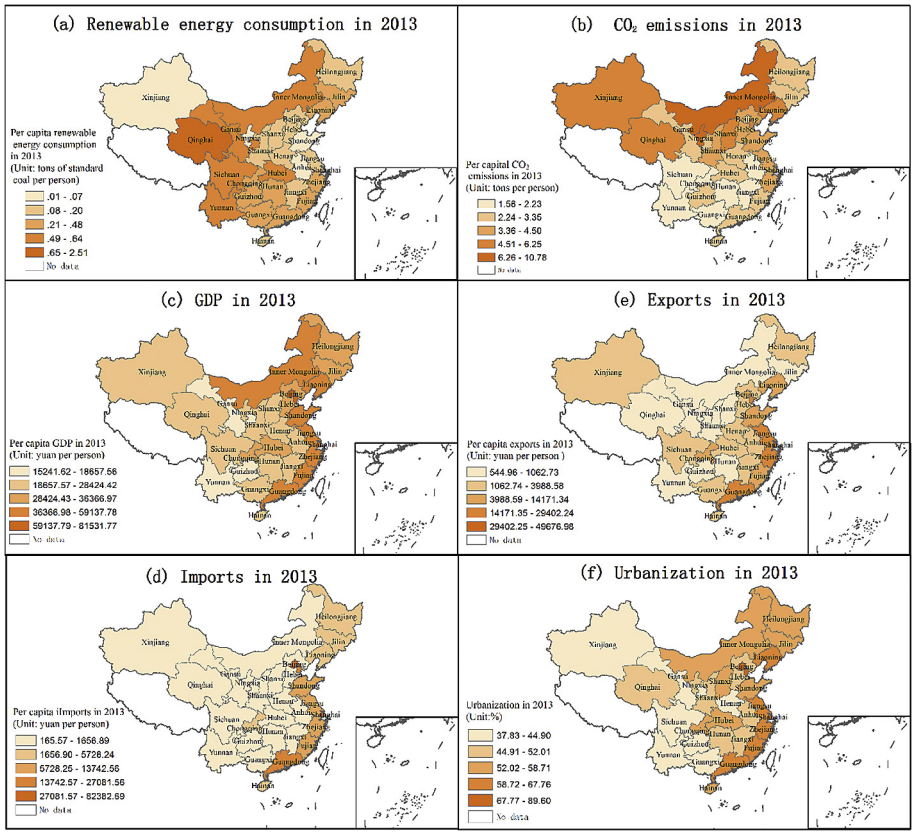

Fig. A.2. Per capita renewable energy consumption, CO2 emissions, GDP, exports, imports and urbanization in 2013.

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